Performance Studies of a Multiwire Chamber, with 1 mm Anode Wire Spacing, to be used for 2-D Position-Sensitive Detection of X-Rays*

E. Mathieson
Leicester University, Leicester LE1 7RH, England

and

G. C. Smith
Brookhaven National Laboratory, Upton, NY 11973, USA

ABSTRACT

Experimental and theoretical studies have been made of the performance of a multiwire chamber, with 1 mm anode wire spacing, to be used for position-sensitive detection of x-rays. The chamber has a wire upper cathode, with the wires parallel to the anode wires. The studies have shown that, from considerations of the spacing and registration of the cathode wires, some useful improvements in performance can be obtained. These improvements concern both position modulation and gain modulation, normal to the anode wire direction.

1. INTRODUCTION

Studies have been made of certain factors relating to the performance of a small (10 x 10 cm.) multiwire proportional chamber. The proposed chamber is to be employed for the two-dimensional imaging of synchrotron x-rays, so that a small anode wire spacing, 1 mm, has therefore been chosen. Considerations of cathode induced charge magnitude then demand an anode, cathode spacing of a similar amount; 1 mm has been chosen for the present chamber. In order to achieve high detection efficiency the chamber's top cathode is a wire cathode with the chamber itself preceded by a drift region of 4 mm. The studies reported in this paper concern i) the position modulation due to the discrete anode structure and, ii) the gain modulation due to small anode wire spacing.

Because of the discrete nature of the anode in a MWPC, the position response normal to the anode wire direction, in a conventional system, is highly non-linear; the uniform irradiation response (UIR) shows strong peaks at the anode wire locations. In fact, because of the marked angular localization of the anode avalanche, it is possible, by employing the induced signals from neighboring anode wires, to interpolate quite accurately between anode wire positions [1,2]. This method does not yet, however, appear to have been applied to a full plane of anode wires. The most successful interpolation scheme has been to "deconvolute" the non-linear position response by on-line computation of the cathode strip signals. The computed position was corrected by reference to a previously calibrated look-up table [3]. The presently proposed scheme has similar features but, from considerations of the imaging wire cathode geometry, the degree of correction necessary has been significantly reduced.

In the present chamber the top cathode wires are parallel to the anode wires, have the same spacing (1 mm), and also register with the anode wires, i.e. a cathode wire is vertically above each anode wire. This particular geometry has advantages relating to both the topics listed above.

In connection with i), consider the field plots shown in Fig. 1(a). The x-direction is normal to the anode and cathode wire direction, and the wires are situated at integral

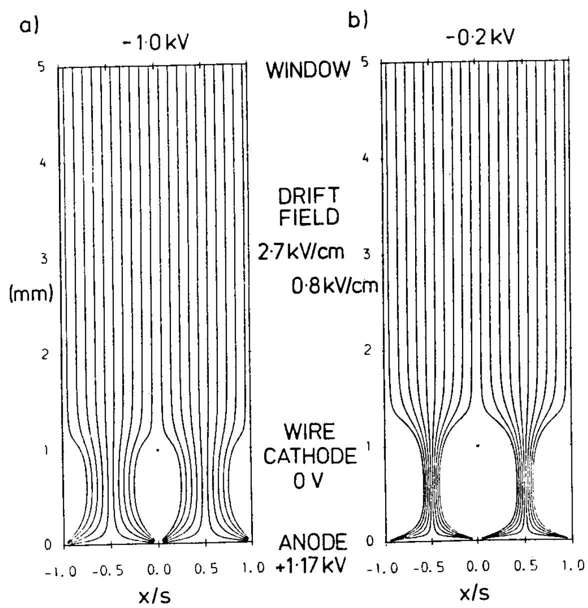

Fig. 1 Diagram of the field lines originating in the drift region for window voltages of a) -1.0 kV and b) -0.2 kV. (Note that line densities in the drift region have been made equal.) s is the anode wire spacing and the cathode wire spacing, x is the distance measured normal to the wire direction. The wire positions are at integral values of x/s.

*This research was supported in part by the U. S. Department of Energy: Contract No. DE-AC-02-76CH00016.

values of x/s, where s is the wire spacing. Primary electrons from an x-ray absorption event at x/s in the drift region will drift approximately along field lines, experiencing diffusion, and then avalanche, with a finite angular spread, at an anode wire, or at two neighboring anode wires. It is clear qualitatively that, near $x/s = 0$, the angular position of the avalanche centroid varies very rapidly with x/s. Now provided the differentiating time constant of the cathode amplifiers is not too small, then the average positive ion movement in this time has a significant horizontal component. Thus the induced charge centroid, x'/s, even near $x/s = 0$, has a quite strong, useful dependency on event location x. A detailed theoretical treatment of the system, taking into account diffusion in the drift region, supports quantitatively this brief qualitative argument. The experimental examination of this situation is described below.

The second advantage of the cathode geometry employed for these studies concerns the angular variation of gas gain. Theoretical studies show that this variation is significantly reduced compared with that with a continuous cathode. Experimental evidence of this effect is also given below.

2. APPARATUS

The prototype chamber employed for these studies consisted of a plane of anode wires, 10 μm diameter at 1 mm pitch, a grounded continuous lower cathode and a grounded upper wire cathode. The cathode wires, 50 μm in diameter, were also at 1 mm pitch and were in register with the anode wires. The anode to cathode spacings were both 1 mm and the drift depth between the upper wire cathode and the conducting, insulated window was 4 mm. The chamber could be filled with $A/20\%CO_2$ or $Xe/10\%CO_2$ at atmospheric pressure and was normally operated at an anode charge of about 0.1 pC, for 5.4 keV incident x-ray energy.

For the present studies the central eleven cathode wires only were employed for position encoding, and they were used in two ways. Firstly, they could be connected to the eleven channels of a centroid-finding filter system [4]. Secondly, they could be connected to form three output nodes only, by connecting wire 1 to wire 4, 2 to 5, 3 to 6, etc., etc. This latter arrangement will be referred to below as the grouped cathode wire arrangement.

3. INTER-ANODE INTERPOLATION

a) Measurements with centroid-finding filter system.

Figure 2 shows the result of traversing across half a wire spacing with a finely collimated (15 μm) beam of 5.4 keV x-rays. The chamber gas was $Xe/10\%CO_2$, the anode voltage 1.17 kV and the window voltage -1.0 kV, as for Fig. 1(a). The cathode amplifier differentiating time constants were 1.4 μsec. It can be seen that a practically useful linear relationship has been obtained between x' and x. A striking illustration of the effect, with this geometry, of time constant is shown in the UIRs of Fig. 3. The decrease

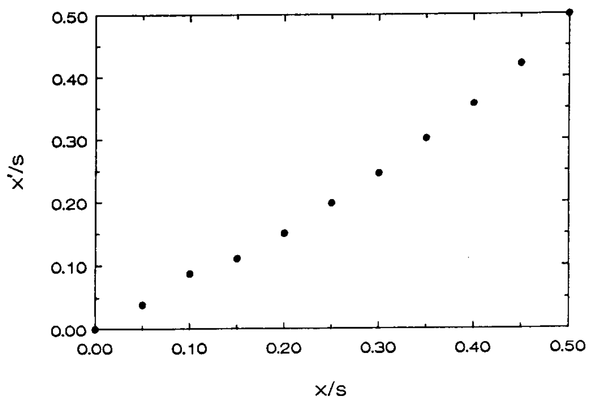

Fig. 2 Output position x'/s as a function of input position x/s, measured with the centroid-finding filter system (4) connected to the cathode wires. The filling gas was $Xe/10\%C0_2$ and x-ray energy 5.4 keV. Cathode amplifier time constant 1.4 μsec.

in differential non-linearity as the amplifier fall time is increased, as predicted in Section 1, is well demonstrated here. Effectively, the bin width has been decreased from s to $s/2$. Of course in practice it is generally not possible to employ such long differentiating time constants as in this demonstration. At lower x-ray energies, however, a large fraction of events could still be absorbed in the drift region using argon filling gas. Then, because of the higher ion mobility in argon compared with xenon, shorter time constants could be employed.

Figure 3(e) shows the effect of decreasing significantly the drift field value, as in Fig. 1(b). The peak positions now correspond to mid-way between anode wires. This effect may be interpreted as follows. For the field configuration of Fig. 1(b) the electron cloud from any absorption position in the drift space must drift through the pinched central region of the chamber. Diffusion in that region then ensures that considerable sharing between two adjacent anode wires takes place and therefore that avalanches of comparable magnitude occur on the two wires. A position output signal near $s/2$ is thus obtained.

b) Measurements with the grouped cathode wire arrangement.

Initial studies have also been made of an approach which may enable the computation of a position signal to be somewhat simplified. A fine/coarse system is being examined in which a fine position is derived from cathode wires connected into just three groups, as described in Section 2. The coarse position is the avalanche wire position. The feasibility of this encoding method has not yet been fully explored; the discussion in the paragraph below is therefore limited to the determination of the fine position only. Nevertheless, the following very brief general remarks may be made. It is considered, at present, that the avalanche anode number may be obtained using relatively simple amplifiers, one per anode wire, followed by a system of

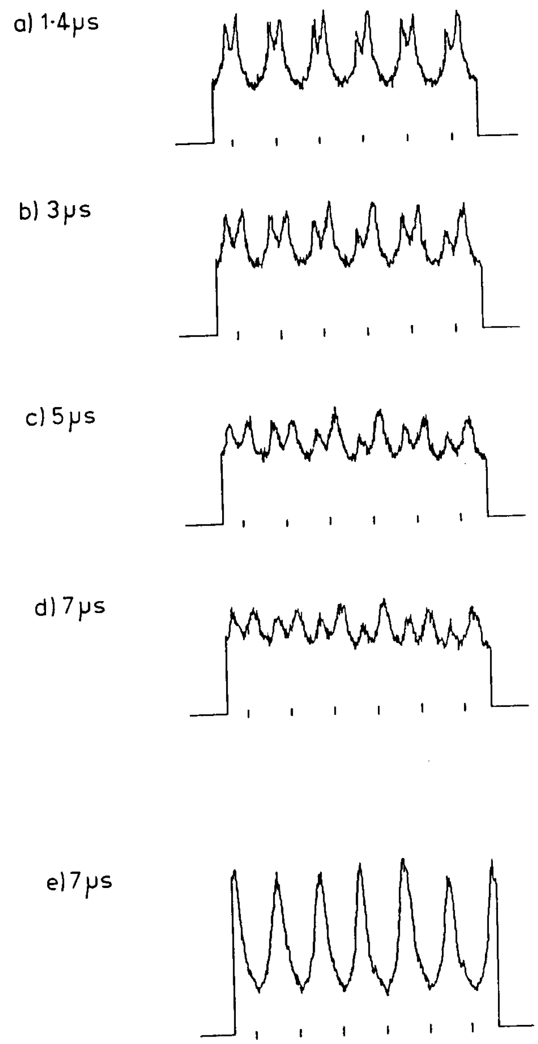

Fig. 3 Uniform irradiation responses measured with the centroid-finding filter system. a) to d) window voltage -1.0 kV. e) window voltage -0.2 kV. Small vertical tick marks indicate positions of the anode wires.

priority encoders. A logic system has been planned which, in principle, can ensure that the cathode-derived fine position is centered over the correct anode-derived coarse position. However, no experimental examinations have yet been made of these proposals.

Let the three cathode wire groups be denoted by A, B and C and suppose that the cathode wire having the largest induced charge belongs to group B. Then a position signal, v_r, can be obtained by evaluating the expression

$$v_r = \frac{(q_C - q_A)}{(q_A + q_B + q_C)}$$

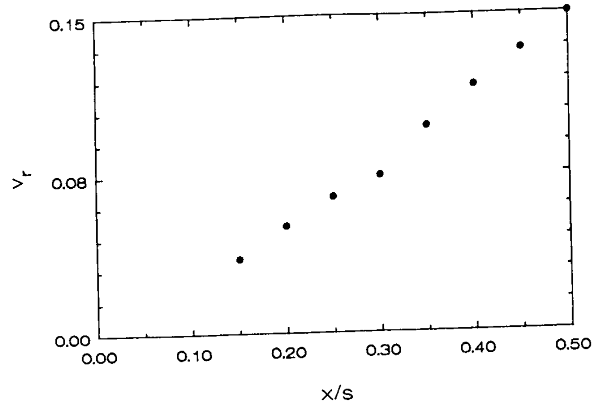

Fig. 4 Output position signal v_r as a function of input position x/s, measured with the grouped cathode wire arrangement. The filling gas was Xe/10%Co_2 and X-ray energy 5.4 keV. Cathode amplifier clipping time 1 μsec.

where q_A, q_B and q_C are the induced charges on the groups A, B and C, respectively. Experimental values of v_r as a function of x/s are shown in Fig. 4. These data were taken with Xe/10% CO_2 filling gas, and with cathode amplifier delay line clipping at 1 μsec. The division in the expression above was accomplished using analogue circuitry; in a final system, digital signal processing would be favored. It should be noted that the linearity is not markedly worse than that obtained using independent cathode wires, Fig. 2. The sensitivity is of course lower, about 0.28 for the grouped arrangement compared with 1.0 for independent cathode wires. Experimental values for position resolution are shown in Fig. 5, for both the photopeak energy, 5.4 keV, and the escape energy 1.5 keV. The mean widths, FWHM, are about 0.035 (125 μm) at 5.4 keV and 0.055 (200 μm) at 1.5 keV.

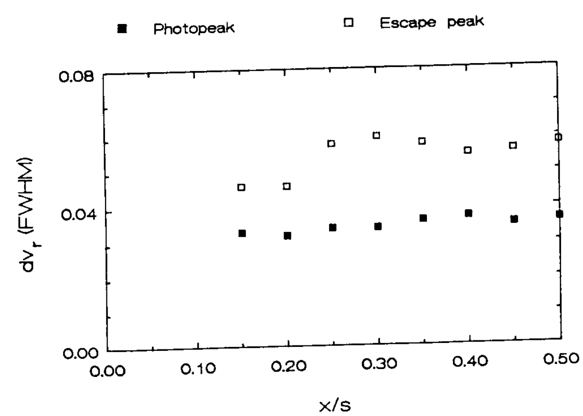

Fig. 5 Measured position resolution dv_r (FWHM) for the grouped wire arrangement. Average values are 0.035 (125 μm) at 5.4 keV and 0.055 (200 μm) at 1.5 keV.

It is estimated that the electronic noise contribution is about 0.013, and the photoelectron range contribution is about 0.018 (65 μm) at 5.4 keV and essentially zero at 1.5 keV. Thus the net, major contributions to resolution are, for the two energies, roughly 0.027 (95 μm) and 0.053 (190 μm), respectively. Their ratio, 0.51, is close to the quantity $(5.4/1.5)^{-1/2}$. This suggests that, as expected, the main contribution to width, in this energy range, is partition noise, i.e. fluctuations in the distribution of the primary electrons round the avalanche wire or, near a mid-point position, between adjacent wires.

4. GAIN MODULATION

The gas gain in a MWPC varies with avalanche angle because of the noncoaxial field near the wire. The observed anode charge varies also with avalanche angle because of the dependence of the relative anode and cathode induced charges on this angle. These two effects are well understood and have received simple theoretical treatments [5], and some experimental examinations [6]. The net gain modulation is predicted to increase quite markedly as the anode wire spacing is decreased; systematic experimental study at small spacing does not, however, appear to have been made.

Figure 6 shows predicted gain modulations for a chamber with a continuous cathode and for a chamber with a wire cathode. A charge measurement time of 2 μsec and an rms avalanche spread of 35 degrees have been assumed. The predicted difference, nearly 8% and just over 1%, is quite striking. Figure 7 shows experimental measurements of the modulation in the two geometries, with $A/20\%CO_2$ filling gas. These measurements confirm the marked reduction in gain modulation that can be obtained with the present cathode geometry.

5. DISCUSSION

It has been shown that, by employing a wire cathode with the same pitch and phase as the anode, it is possible to counteract to some degree the positional modulation due to the discrete anode structure. The correction required to interpolate linearly between anode wires should therefore not degrade seriously the positional resolution.

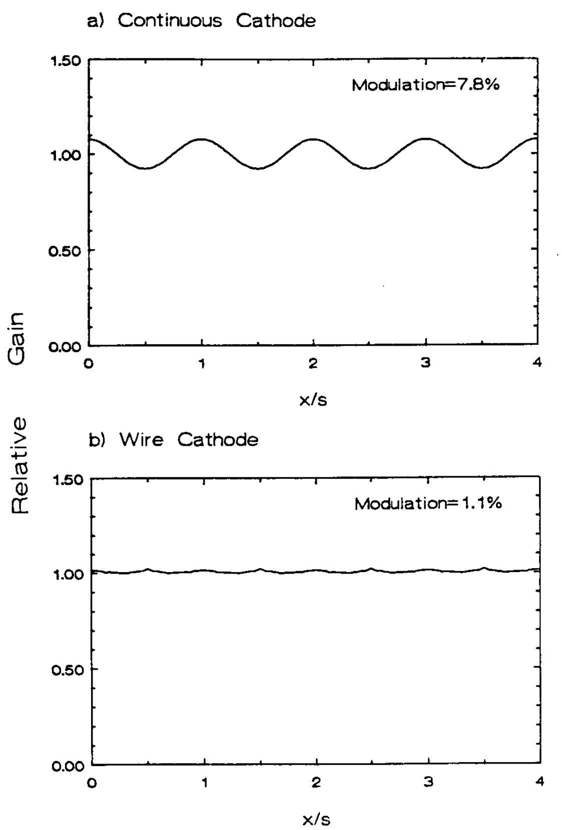

Fig. 6 Predicted gain modulation normal to anode wire direction. a) continuous cathode, b) wire cathode. Anode charge calculated at 2 μsec. An avalanche spread of 35 deg. rms and a positive ion mobility of 2 cm^2/Vs have been assumed. Wire spacing and anode, cathode spacing as in text.

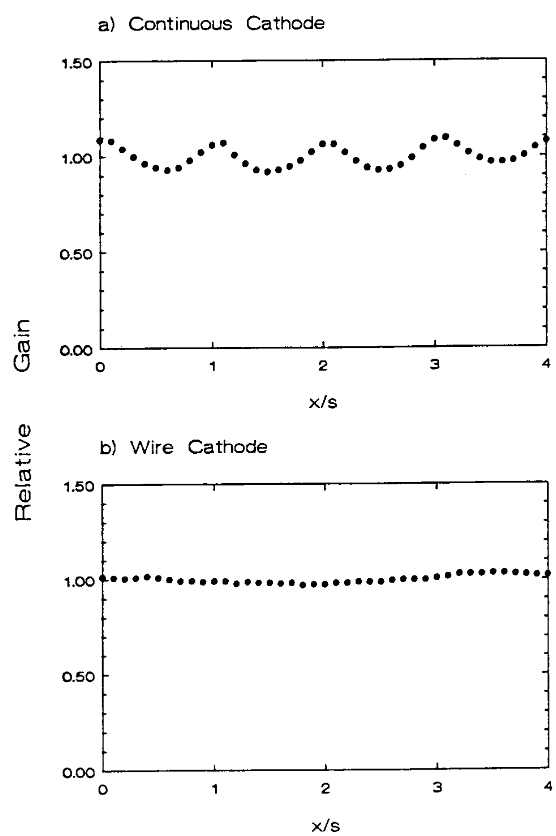

Fig. 7 Experimental measurement of gain modulation normal to anode wire direction. a) continuous cathode, b) wire cathode. Anode charge measured at 2 μsec. Filling gas, $A/20\%CO_2$. The ordinate represents the most probable pulse amplitude of the photopeak from 5.4 keV x-rays.

A further study has indicated that, by connecting the cathode wires in groups, a fine/coarse system may be possible in which only three high quality cathode amplifiers would be required. The determination of the coarse (anode wire) position would require an amplifier per anode wire, but these could be of lower performance and simpler construction. In summary, the present 'fine' system has been shown to achieve, for 1 mm wire spacing, a resolution of 125 μm FWHM at 5.4 keV x-ray energy.

Finally, it has been demonstrated experimentally, confirming theoretical prediction, that gain modulation due to small anode wire spacing can be almost eliminated with the present cathode geometry.

6. ACKNOWLEDGEMENTS

The detector was carefully assembled by Gene Von Achen. We have had useful discussions with Trevor Harris (Leicester) and Joe Harder (Brookhaven) concerning the electronics of various position encoding methods.

7. REFERENCES

[1]. G. Charpak, G. Petersen, A. Policarpo and F. Sauli,"Progress in High-Accuracy Proportional Chambers", *Nucl. Instrum. Methods* vol. 148, 471-482 (1978).

[2]. T. J. Harris and E. Mathieson, "Angular Localisation of Proportional Chamber Avalanche", *Nucl. Instrum. Methods* vol. 154, 183-188 (1978).

[3]. G. Charpak, G. Melchart, G. Petersen and F. Sauli, "High-Accuracy Localization of Minimum Ionizing Particles Using the Cathode-Induced Charge Centre-of-Gravity Read-Out", *Nucl. Instrum. Methods* vol. 167, 455-464 (1979).

[4]. V. Radeka and R. A. Boie, "Centroid Finding Method for Position-Sensitive Detectors", *IEEE Trans. Nucl. Sci.* vol. 27, 351-362 (1980).

[5.] E. Mathieson and T. J. Harris, "Modulation of Anode Signal in Multiwire Proportional Chambers", *Nucl. Instrum. Methods* vol. 157, 563-565 (1978).

[6.] P. J. Gilvin, E. Mathieson and G. C. Smith, "Anode Modulation Effects in Multi-Wire Chambers", *Nucl. Instrum. Methods* vol. 163, 279-280 (1979).